REMARKS

The Office action of October 10, 2002 has been carefully considered and the application has been amended accordingly,

Claims 1-8 have been rewritten as new claims 9-16 and include the changes required by the Examiner.

New claims 17-24 generally correspond to claims 9-16 but have been written in the form of method claims rather than apparatus claims.

The Abstract has been presented on a separate page to be attached at the end of the specification.

The Examiner's rejections upon prior art are believed to be in error in view of the following arguments which are applicable to apparatus claims 9-16 and method claims 17-24.

The examiner has suggested that the invention is obvious, referring to US 2 578 505 (Carlin) and US 4 369 100 (Sawyer). It is not clear that a rejection is based upon Sawyer, but the Examiner mentions it in the Office action. These patents relate to apparatus that includes a tube provided with several ultrasonic transducers. However, in both patents the transducers are well spaced apart: in Carlin the gap between one transducer and the next is approximately the same as the width of the transducer, while in Sawyer the gaps are about twice the width of the transducers. In neither case can it realistically be suggested that the transducers are closely arrayed. There is thus

a clear structural difference between the apparatus of the present invention and that of these citations. This arises from the recognition, in the present invention, that although a large power deposition (per litre) is desirable, it is important not to have a large power intensity (per square cm), otherwise cavitation blocking will occur and the range of the ultrasound will be severely restricted.

The examiner also suggests that Carlin and Sawyer would render the present invention obvious, because "the difference between Carlin and the present invention "is the manner of operating the apparatus". The examiner appears to recognize that there are several features of the present invention that are not suggested by the prior art, but he seems to consider that they relate to the manner of operation rather than to the apparatus itself. The invention as claimed in claims 9-16 imposes restrictions that are of a structural nature: the size of the vessel being recited as "large enough that each transducer radiates into fluid at least 0.1 m thick", the spacing between the transducers, and the number of transducers being "sufficiently close to each other, and .... sufficiently high, that the power dissipation... is at least 25 W/litre ...." The other parameter that is specified is the power intensity of each transducer is "no more than 3 W/CM2..." which does restrict the type of transducer -- as some ultrasonic transducers are not

designed for use at such an intensity. It is acknowledged that the power dissipation occurs only during operation; nevertheless, there are clearly several limitations and restrictions, as claimed, that are being placed on the apparatus itself. Applicants therefore assert that those limitations provide a clear distinction, and indeed a non-obvious distinction from Carlin and from Sawyer. Further, method claims 17-24 have been presented to more clearly define the process steps inherent in the invention.

In considering the phenomenon of "cavitation blocking", it will be appreciated that for optimum acoustic power transfer between the transducer and the liquid the acoustic impedances of the successive media should be matched as closely as possible. But even if there is good matching, the ultrasound will not necessarily propagate very far in the liquid. For example, with a piezoelectric transducer connected via an aluminum coupling block as shown in FIG. 1 of the present application, as the power intensity (adjacent to the wall) is increased the resulting cavitational effects also increase; but considering a position say 0.5 m into the liquid, the cavitational effects reach a maximum at an intensity (adjacent to the wall) about 2 W/CM2, and if the intensity is increased beyond that value the cavitational effects rapidly decrease, becoming negligible at an intensity of about 2.5 W/cm2 (the exact values will of course differ for

different liquids). At these high intensities -- say above 3 W/CM2 -- there is intense cavitation immediately adjacent to the wall to which the transducers are connected, but the cavitation effectively blocks further transmission of the ultrasound. This is why in US 4 556 467 (Kuhn et al), for example, 20 kHz waves are indicated as having a range of only about 25 mm (column 5 line 63) -- at an intensity of say 5 or 10 W/CM2 the intense cavitation adjacent to the wall will prevent ultrasound propagating any further than that. In contrast, at lower values of ultrasonic intensity such as 2 W/cm^2, the ultrasound can propagate as much as 1 m, causing cavitation throughout that depth.

The present invention takes this "cavitation blocking" phenomenon into account, and enables high power deposition (say 50 or 80 W/litre) over a large volume, by having a very large number of transducers close together, and ensuring that the ultrasonic power intensity is sufficiently low that cavitation blocking does not occur. This is contrary to the teaching of the prior art, in which it is presumed that high power deposition is achieved by increasing the ultrasonic intensity.

The examiner has also suggested that the claims are obvious in the light of US 6 361 747 (Dion *et al.*) It will be appreciated that there are clear structural differences between the apparatus and method claims of the present invention and the disclosure of

Dion et al. In the present invention the transducers are attached to an inner or outer wall of the vessel, whereas in Dion *et al.* the transducer assemblies are arranged to be close to, but not touching, the wall of the vessel, and a layer of oil 9 is provided as a couplant. This has considerable analogies to the use of oil as a couplant in the apparatus of Desborough *et al.* (US 5 658 534) where again it is because very high intensities are sought (>12 W/cm^2, considering the electrical power input). The intention to obtain high power intensities is also evident in Dion *et al.* from the use of coupling blocks 8 that taper, being narrowest adjacent to the wall of the tubular vessel, so as to increase the power intensity at the wall. This is emphasized at column 8 lines 32-36. (In contrast, in the present invention, the coupling blocks are widest next to the wall!) It will also be appreciated that Dion *et al.* require the use of coupling bars in the form of prismatic bars with considerable longitudinal extent, with apparently 10 such bars arranged around the tubular vessel to judge from FIGS. 2 and 6 (the number is said to be typically between 4 and 16 -- column 6 lines 65-67); in contrast the present invention specifies an array of separate transducers, the array extending both longitudinally and also circumferentially.

This citation, Dion *et al.*, gives no numerical information concerning power intensity at the wall, or power deposition within the vessel, so can hardly be said to render the numerical

limitations of the present invention obvious. Nor does the patent appear to provide any information about the size of the apparatus, whereas the present invention specifies that the diameter must exceed 0.1 m. Since none of these limitations is taught by Dion *et al.*, the present invention is clearly not rendered obvious.

Attached hereto is a copy of publicity material that describes the equipment of the Dion *et al.* citation, that has been distributed by the assignee of that US patent, Sonertec; the publication date of which is not known by applicants. This material provides some further numerical information, indicating that the prototype equipment has a volume of 1 litre into which 2 kW are dissipated. The intention is to increase the power deposition. The full-scale reactor will have a reaction chamber of 14 litres and a power input of 50 kW (see page 2 paragraph 3). The figures for power deposition are far greater, namely, 2000 W/litre for the prototype, and 3571 W/litre in the "full-scale reactor". Even the value of power deposition in the prototype is more than 12 times greater than the maximum value permitted by the present invention.

Assuming, from FIG. 1 of the Dion *et al.* patent, that the length of the reaction chamber is about 6 times its diameter, that would indicate that the radius of the prototype equipment described in this brochure is 3 cm, and that the intensity at the

surface of the wall is about 5.9 W/cm^2. That would suggest that none of the parameters specified by the present invention is anticipated by this citation!

The examiner has taken the position that original claim 4 (corresponding to new claims 12 and 20) is obvious in the light of Dion et al in conjunction with Desborough *et al.* These patents, as mentioned above, are clearly both aiming to achieve very high intensities; and also as mentioned above, they both utilize oil as a low-attenuation buffer liquid between the transducer assemblies and the outside of the wall of the vessel. Neither citation suggests use of a double-walled container. Further, neither citation suggests the numerical limits on power intensity at the wall, or on power deposition, that are the characterizing features of the present invention. Hence, claims 12 and 20 can hardly be considered obvious in the light of these citations -- neither singly, nor in combination, do they suggest the numerical limits on power intensity, or those on power deposition, nor the use of a double-walled container.

The examiner has also rejected original claims 7 and 8 (corresponding to new claims 15, 16, 23 and 24) in comparison to Dion *et al.* This is a surprising rejection, because Dion *et al.* do not suggest arranging different transducers to resonate at different frequencies. Indeed, none of the citations appear to suggest this inventive idea.

In view of the foregoing amendments and remarks, applicants believe that the application is now in condition for allowance of claims 9-24 and such action by the Examiner is courteously solicited.

Respectfully submitted,

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In a preferred embodiment the vessel is double walled, the transducers being attached to the outer wall, the fluid to be treated being enclosed within the inner wall, and the space between the two walls being filled by a low attenuation buffer liquid whose cavitation threshold is above that of the liquid to be treated.

The width of the gap between the two walls is desirably equal to a quarter wavelength in the coupling liquid (which for a frequency of 20 kHz would be about 18 mm), or an odd-numbered multiple of that distance, to optimise the matching of impedance.

In one embodiment some of the transducers are energized at one frequency and other transducers at a different frequency, for example at 20 kHz and at 40 kHz. This can be very effective at causing cavitation and energy deposition within a fluid.

The invention will now be further and more particularly described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 shows a longitudinal sectional view through an irradiator apparatus;

Figure 2 shows a longitudinal sectional view through an alternative irradiator apparatus; and

Figure 3 shows a sectional view on the line 3-3 of $\boxed{\text{figure}}$ FIG. 2.

FIG.

Referring to figure 1 an irradiator 10 incorporates a stainless-steel duct 12 of internal diameter 0.31 m and of wall thickness 2 mm. To the outside of the wall are attached sixty transducer modules 14 closely packed in a square array. Each transducer module 14 comprises a 50 W piezoelectric transducer 16 which resonates at 20 kHz, attached to a conically flared titanium coupling block 18 by which it is connected to the wall, the wider end of each block being of diameter 63 mm. The transducers modules 14 are arranged in five circumferential rings each of twelve modules 14, the centres of the coupling blocks 18 being on a square pitch of 82 mm. The irradiator 10 also incorporates five signal generators 20 (only one is shown) each of which drives all the transducers 16 in a ring. All the transducers 16 are activated at 20 kHz.

In use of the irradiator 10, a liquid is caused to flow through the duct 12 and each transducer 16 activated. Each transducer 16 radiates 50 watts over a circle of diameter 63 mm, that is an intensity of 1.6 W/cm^2. The energy from all the transducers 16 is dissipated over the cylindrical volume of the duct 12, that is to say over a volume of about 31 litres (that is the volume enclosed by the array of transducer modules 14), so the power density is about 97 W/litre, or about 80 W/litre if the ultrasonic irradiation is also effective 40 mm beyond each end of the array of transducer modules 14.

In one modification, three of the rings of transducers 16 are as described above, while the other two rings resonate at 40 kHz and are driven at that

or an industrial solvent); at a frequency of 20 kHz the wavelength of the sound in this oil is 72 mm, so that the gap 36 is of width equal to a quarter of the wavelength.

In use of the irradiator 30, a liquid is caused to flow through the duct 32 and each transducer 16 is activated by a power supply (not shown) at 20 kHz. The dissipated power intensity and power density are as described in relation to $\boxed{\text{figure}}$ FIG 1. The impedance matching provided by the oil in the gap 36 allows more of the applied power to enter the fluid within the duct 32 while reducing erosion at the inner, irradiating, surface of the tube 35.

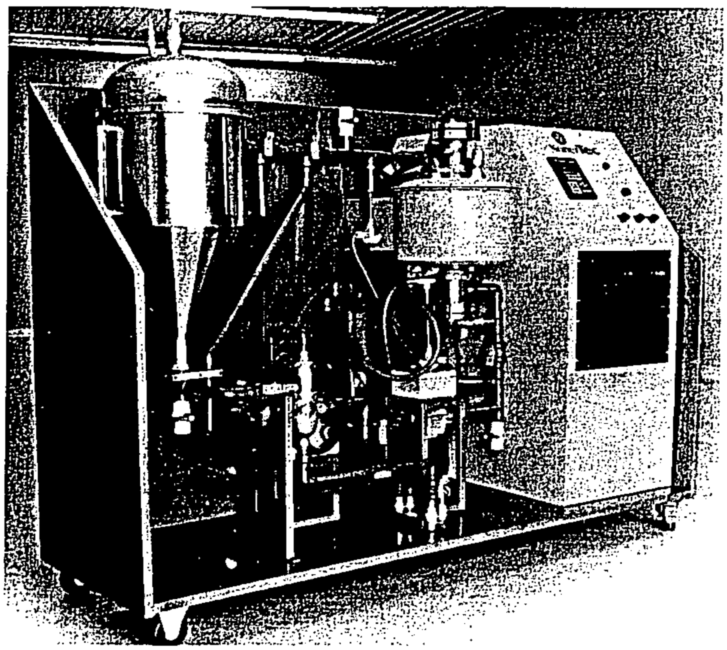
It will be appreciated that the power intensity in the irradiator 30 may be increased by increasing the numbers of transducer modules 14 in each ring. For example there might be sixteen transducer modules 14 in each ring, if the coupling blocks 18 were arranged on a circumferential spacing of 69.5 mm. This would increase both the power density and the power intensity by 33 percent. It will also be appreciated that the duct 32 can be of any material suited to the liquid being processed, and that it may form part of a pressure vessel. It will also be appreciated that the duct 12 or 32 need not be cylindrical but might for example be of square cross-section.

Furthermore the ultrasonic frequencies or frequencies might be different from those described above, and might be as high as 140 kHz or even 200 kHz, as such high frequencies tend to reduce the risk of cavitation erosion.

frequency (the rings being of alternate frequency along the duct 12). The power intensity and power density are as described earlier, but the fluid is consequently exposed simultaneously to two different frequencies generating cavitation. This can produce more effective sonochemical results.

Referring now to ~~figures~~ FIGS. 2 and 3 there is shown an alternative irradiator 30 which has many features in common with that of ~~figure~~ FIG 1. The irradiator 30 includes a generally cylindrical duct 32 of polytetrafluoro-ethylene (PTFE) of internal diameter 0.31 m and of wall thickness 3 mm, which tapers at each end down to an internal diameter of 0.10 m and a wall thickness of 6 mm provided with a flange 33 for connection to other process ducts (not shown), and has a sealed joint 34 for inspection or cleaning purposes. Around the outside of the duct 32 is a concentric stainless-steel ~~steel~~ tube 35 of wall thickness 1 mm and of external diameter 0.354 m, such that there is a gap 36 of width 18 mm between the duct 32 and the tube 35. Sixty transducer modules 14 are attached to the outer surface of the tube 35 in a rectangular array forming five rings of twelve, the spacing between the centres of the coupling blocks 18 being 82 mm parallel to the longitudinal axis of the tube 35 and 92.7 mm circumferentially. The array of transducers 14 is enclosed by an acoustic shield 38. A coupling liquid such as olive oil 40 is used to fill the gap 36 and is re-circulated from a reservoir 42 by a pump 44. This coupling liquid has a higher threshold for cavitation than water, and has an impedance which is between that of the titanium coupling block 18 and that of the fluid within the duct 32 (typically mainly water,

Cylindrical acoustic cavitation reactor



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Acoustic Cavitation Reactors

Informations

THE TECHNOLOGY

The Sonertec Acoustic Cavitation Reactor is a high power electro-acoustic chemical reactor using the well known acoustic cavitation phenomena. Its unique features make it suitable for a large spectrum of applications in the chemical industry as well as in the fields of waste treatment and water decontamination. The construction of two small scale industrial prototypes has been completed and construction of a full size system is starting.

In essence, it is a system which transform with very high efficiency electrical energy into chemical energy through the use of a high power ultrasonic field. The high power ultrasounds produce acoustic cavitation which concentrate the energy into thousands of small bubbles at the center of the acoustic field in a very well defined and controlled area of the reactor. This situation gives rise to a large increase in the kinetics of chemical reactions. The results can range from the fragmentation of solid particles, to the degradation of chemical molecules including the disruption of living cell walls. The effect of cavitation in different systems will vary with the nature of the system and the energy provided to the system.

The industrial prototype has a 1 liter reaction chamber in which we can provide an energy of 2 kW. However, recent developments allow to double the energy put into that reactor to 4 kW (and even more). In the near futur we believe we can double again the energy density in this reactor. The full scale industrial reactor will have a reaction chamber of 14 liters and a power input of 50 kW.

Figure 1 illustrate the unique concept behind Sonertec's reactor. Piezoelectric transducers specially designed for the production of high power converging waves surround a tube. As the waves are produced, they travel toward the center of the tube. The energy density increases as the wave approaches the center of the tube. At one point the energy is sufficient to generate acoustic cavitation. An intense, cylindrical shaped, large volume cavitation zone is created. An important feature of this reactor is that cavitation will be generated away from the surface of the tube avoiding the problem that all other acoustic cavitation reactors have: destruction of reactor walls. All reactors produced by competitors suffer from this problem because the highest energy density is located right at the surface of the walls of the reactors. As is well known, erosion of the reactor walls will inevitably happen.

The treatment unit presented in figure 2 and figure 3 is now in operation. The tests done so far with this system demonstrate its efficiency and reliability.

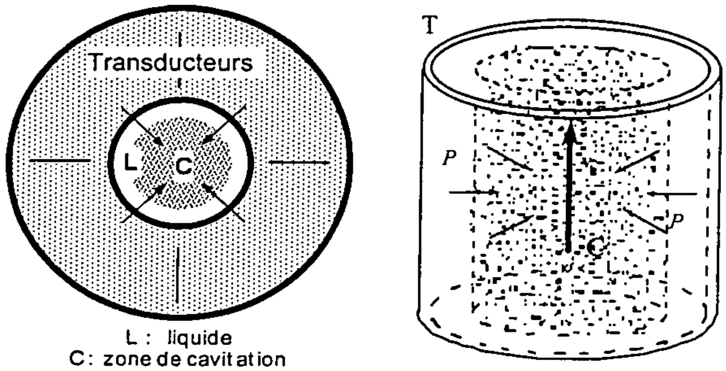

Figure 1 • Principle of operation of the reactor

The liquids, reagents or sludge to be treated will travel through the reactor at a rate which depends on each particular application. A single industrial size reactor could, for low energy requirement applications treat as much as 60 000 tons per year (the variable affecting most the yearly treatment capacity of the system is the required specific energy for the treatment).

Many reactors can be used in series or in parallel to increase processing capacity of a system.

The research program that has been going on for the last years has shown that Sonertec's acoustic cavitation reactor is the world's most energy efficient when compared to the competition. It is also unique in its ability to treat industrial size volume with little wear and without contamination of the reagents.

Interest for industrial applications of acoustic cavitation has been increasing for the last 15 years. This can be realized by looking at the number of scientific publications and by the arrival of a few manufacturers of acoustic cavitation reactors, mainly in Europe.

Despite the interest, very few acoustic cavitation reactors are in operations in industrial settings.

The reason for this is that no reactor with industrial (large volume) capacity is available. This problem is solved with the introduction on the market of Sonertec's reactor.

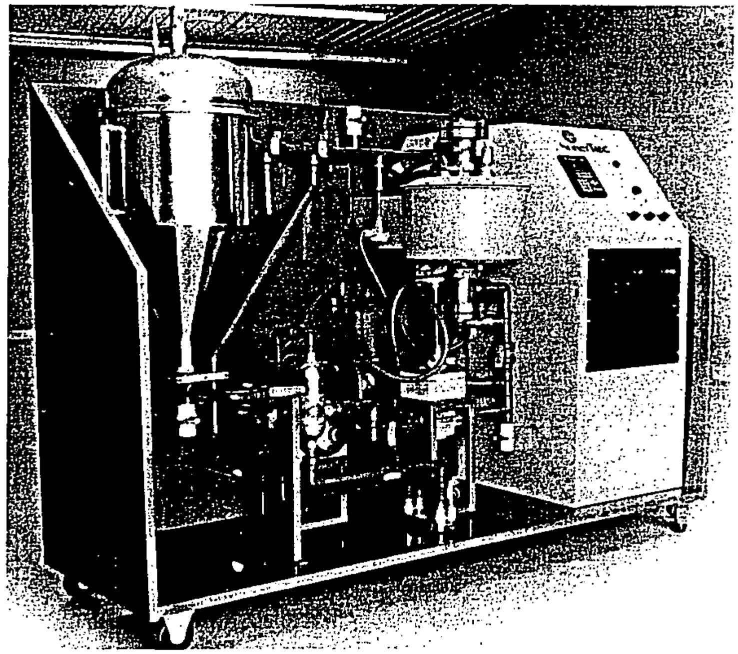

Figure 2 : Picture of a small scale industrial prototype.

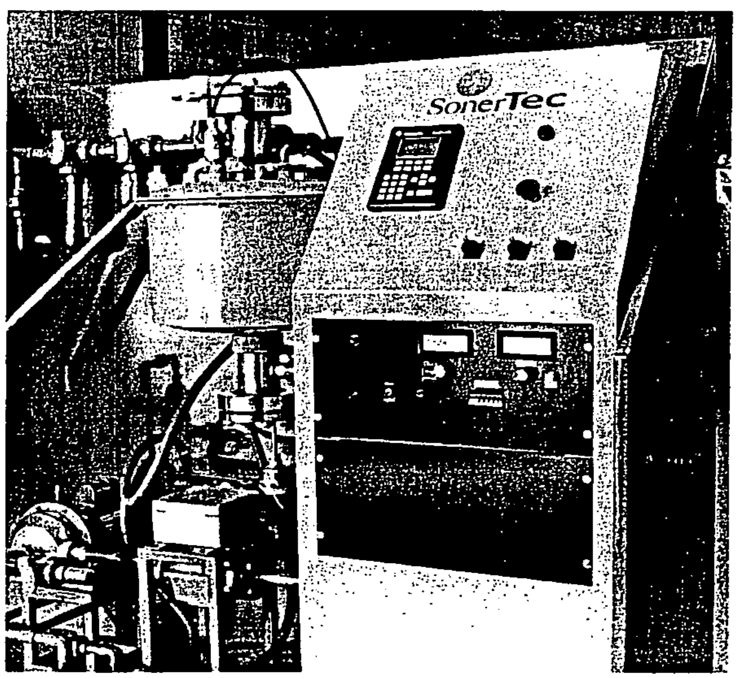

Figure 3: Other view of the small scale industrial prototype. One can clearly see the cylinder (at the back) that contains the reactor and the controls and power electronics up front.

APPLICATIONS

This new acoustic cavitation reactor will replace many existing conventional types of industrial chemical reactors. Its advantages are:

- Water decontamination (sterilization)
- Sludge degradation (industrial and municipal)
- Increased reaction rates for many industrial chemical reactions;
- Increased reaction efficiency;
- Allows for the use of lower quality reagents;
- Increased catalysts activity;
- In some applications, complete elimination of the use of catalysts;

It also can be used for water decontamination with the advantage of not needing additional chemicals for the treatment.

The small scale industrial reactor has been used for the following treatments:

- Industrial and municipal sludge
- Production of nanometric size metallic powders
- Controlled oxidation of food products
- Sterilization of food products
- Oxidation of mineral products.

LARGE CAPACITY REACTOR (SR-42)

Sonertec is now building the SR-42 reactor for large scale industrial applications. This unit has a treatment volume of 14 liters and a power input of 50 kW. It will be available in the first quarter of 2003.

AN OVERVIEW OF ACOUSTIC CAVITATION

Acoustic cavitation is an extremely violent phenomenon which appears as the formation of micro-bubbles or micro-cavities in a liquid where an intense acoustic field is generated. During the low pressure phase of the acoustic wave, the micro-bubbles will be formed. These bubbles will evolve in size as they are subjected to the varying pressure field. At some point, in a high pressure phase of the acoustic wave, the bubble will implode, giving rise to temperatures ranging from 5000 °C to 10000 °C and pressures in the area of 1000 psi.

Figure 6 illustrates the phenomenon. One can see that this figure represents two states of a liquid submitted to a large acoustic pressure (high pressure oscillating between a positive and a negative value: compression and depression). During the depression phase, if the depression is sufficiently low, any discontinuity in the liquid (micro-particles, micro-bubbles, etc) will give rise to a bubble which radius "r" increases from a initial value (small radius) "r_o" which is in the order of 1 micrometer or less. After a few cycles, during the compression phase, the bubble will implode. During the implosion, the temperature inside the cavity will rise to some 5 to 10 thousand degrees and the pressure in the order of 1000 psi will be experienced by the vapors inside the bubble and the liquid surrounding it.

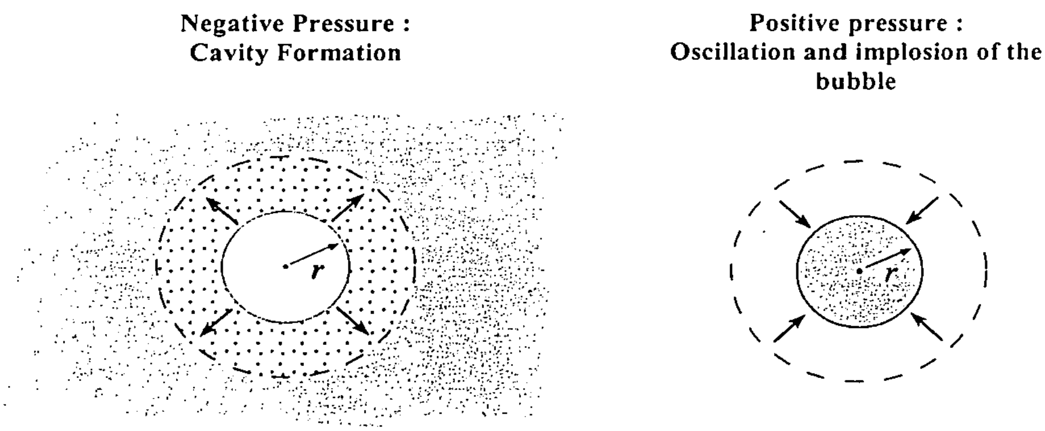

Figure 6 - Acoustic Cavitation: formation and impolsion of a cavity.

The energy released in the during cavitation is so high that it can dissociate water. This creates the most reactive chemical environment imaginable inside this reactor.

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